ANALYSIS OF CHANGE OF TOTAL DRAWING FORCE AND FRICTION FORCE ON PUNCH AT IRONING

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ABSTRACT
Processes of cold plastic forming are characterised by unity of positive and negative influence of outer friction forces; on some contact surfaces of material and tool the friction should be intensified, and in other zones the friction forces must be reduced by lubrication as much as possible. In ironing process, tribological conditions, i.e. realized friction forces, play a significant part.
The main factors at ironing are: forming speed, strain ratio (depends on load and semi-angle of the die cone), condition of materials in contact (surface topography, physical and chemical properties of materials), type of lubricant and geometry of tool and work piece. By proper selection of influential process parameters it is possible to obtain work piece of satisfactory quality with minimal energy consumption.
In this paper, a detailed analysis of influence of specified parameters on total ironing force and friction force on punch will be shown on adequate tribo-model of sheet-metal test-piece sliding between pairs with skewed contact surfaces.
The results of detailed researches show that ironing force and friction force on punch, on sliding path, can be constant, can increase, decrease or even be of a combined character.

KEYWORDS: Ironing, Ironing force, Friction force

1. INTRODUCTION

Ironing is applied for manufacture of cylindrical parts whose depth is larger than diameter, and bottom thickness larger than wall thickness, such as bushes, thin-wall pipes, damper casings, fire extinguishers, gas balloons, oil filters casings, piston engine cylinders liners and especially food and drink cans, whose annual production in the world comes up to billions of pieces. The specified parts are made out of materials which have sufficiently high plasticity in cold condition, such as low-carbon steels, austenitic stainless steels, aluminium, brass and others. Figure 1 shows some parts obtained by this procedure.
The influence of tribological factors at ironing is extremely important and has been the subject of

Figure 1: Examples of some parts manufactured by ironing.

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study of many researchers in the last few years, both in real processes and on tribo-models. Investigation of tribological conditions in real processes is considerably longer and more expensive, so investigations on tribo-models are performed more often.

Ironing force represents a very important value in the ironing process, because the consumed power (energy) for process execution depends on it. Because of that, the ironing force is a very frequently analysed value. On the other hand, ironing force represents output value of the process, together with piece quality. Ironing force depends, more or less, on all relevant process parameters.

At ironing, as well as in other metal forming processes, sliding path is usually limited and the conditions keep changing from the beginning until the end. First of all, on that path the temperature of contact pairs and contact pressure can increase, and then there is the influence of realised wear products, change of relative sliding speed etc.

Various dependences of friction force, and thus ironing forces, starting with the sliding path, can be classified in the following way /1/:

1. friction force does not depend on sliding path (it is constant all the way) (Figure 2a),
2. the force is constant on one part of the path, after which it starts increasing (Figure 2b),
3. friction force increases continuously (Figure 2c) and
4. friction force decreases continuously (Figure 2d).

The first case relates to the application of active lubricants. It can be assumed that the lubricant layers are steady and they do not get disturbed in the friction process, and thus micro-welding of roughnesses peaks does not occur. Friction coefficients obtained in this case can be both very low and very high, which depends primarily on the type of lubricant.

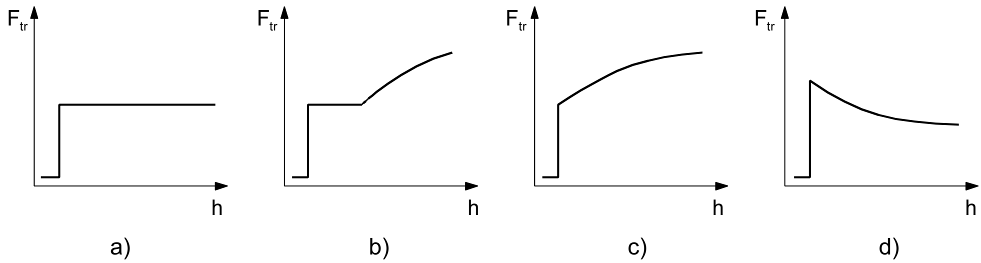


Figure 2: Typical cases of friction force Ftr dependence on sliding path h, /1/.

The second case most often occurs when applying bad or inadequate lubricants, whereat, after certain time, they get extruded out of the contacts, which causes the direct contact of metals, and in that way micro-welding of roughnesses peaks or the intrusion of roughnesses peaks of harder tool into the softer forming material. Increase of friction force is, also, closely connected to specific contact pressure. For example, with one and the same lubricant at small contact pressure the first case of dependency occurs, while at higher pressures the second case occurs. This indicates that such a lubricant is not suitable for high contact pressures.

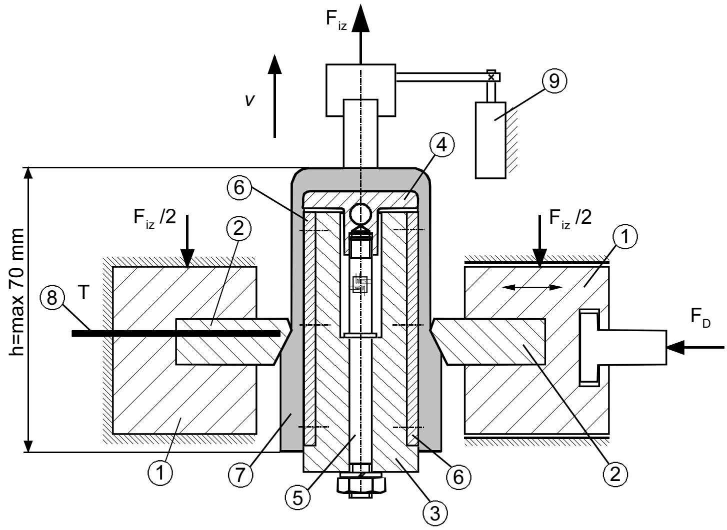
The third case is connected to the application of high-effective lubricants. Very often all of the lubricants form relatively thick layers. Although it can be assumed that, in that case, the reason for increase of friction force is the appearance of micro-welding and intrusion, it is still hardly probable if the absolute values of friction coefficients are small. Temperature changes in lubricant layer, which influence its properties, are more likely the reason.

The fourth case appears most often when applying MoS_2 as a lubricant which forms thick lubricant films. During the relative sliding of surfaces, lubricant extrusion, i.e. reduction of its thickness, appears which leads to decrease of friction coefficient.

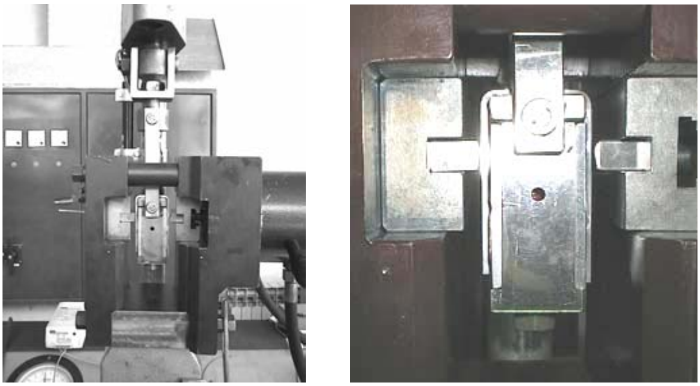
Considerations of dependence of friction force (friction coefficient) on sliding path, show that at constant speed of relative sliding and pressure, the most general dependence corresponds to a horizontal line, which then continues to rise (Figure 2b). That increase confirms the sharp quality change of friction conditions and transition from stable to unstable process. Thereat, that transition is followed by development of micro-welding. Disruption of stability also leads to heating, lubricant rupture and further increase of friction force up until total welding (galling). The existence of surface-active substances in the lubricant makes easier breaking of micro-welding points and enables the elimination of their catastrophic rise and disruption of process stability. In the stable process, the number of new micro-welding points should be equal to the number of broken points. If point-to-point micro-welding does not occur, friction coefficient value will depend only on structural and mechanical properties of the lubricant, whereat at thick lubricant layer both increase and decrease of friction coefficient are possible with the path elongation and reduction of lubricant film thickness.

2. EXPERIMENTAL RESEARCHES

Investigations which were carried out on the original tribo-model of ironing, which with bilateral symmetry imitates the zone of contact with die and punch /2/. This model enables realization of



a)



b)

Figure 3: Scheme and appearance of model used in this paper.

high contacting pressures and takes into consideration physical and geometrical conditions of the real process (material of die and punch, topography of contact surfaces, die cone angle - α etc.). The scheme of specified tribo-model is given in Figure 3a, and appearance of device in Figure 3b.

Bent sheet metal 7 band, shaped like letter U, (test-piece), is placed on the "punch". It is acted upon by "dies" 2 with force F_D. Dies are placed in supports, whereat the left support is motionless, and the right one is movable together with the die. The punch consists of body 3 and front 4 which are inter-connected by gauge with measuring bands 5.The test-piece is ironed (it slides) between dies due to the effects of force F_{iz} on the punch front, in the course of which the test-piece is ironed. Throughout ironing, the outer surface of test-piece slides over die surface (skewed at an angle α), and inner surface of test-piece slides over plates 6 fixed onto the punch body.

The device is made with possibility for simple modification of contact – pressing elements (die 2 and plate 6), easy cleaning of contact zones and convenient placing of test piece.

Plates 6 and dies 2 can be made of various materials, and with different roughness, and dies can be made with different cone semi-angle α.

On the specified device, it is also possible to simulate successive (multistage) drawing, whereat one and the same test-piece is ironed between contact pairs several times.

Device for ironing is installed on the special machine for investigation of sheet metals ERICHSEN 142/12.

Total ironing force F_{iz} represents the sum of friction force between punch and work-piece, F_{trI}, and force that acts upon the test-piece bottom, F_z (Figure 4), that is:

$$F_{iz} = F_{trI} + F_z . \quad (1)$$

Force F_{iz} is measured on the machine itself, and friction force on punch side F_{trI}, is registered with the gauge with measuring bands.

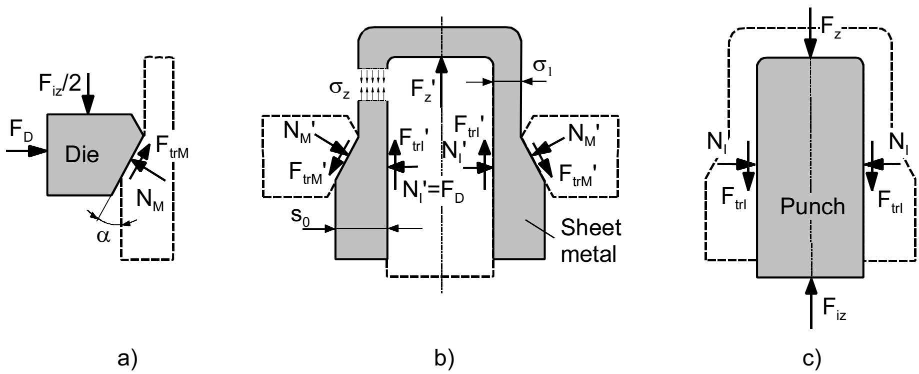


Figure 4: Scheme of forces effects: a) on die, b) on sheet metal, c) on punch.

The process of pieces manufacture by ironing is influenced by many factors. They can all be divided into four main groups:

- influential factors which depend on the object of forming (material, dimensions and shape of the piece),
- influential factors which depend on the tool,
- influential factors which depend on the machine, and
- influential factors which depend on contact conditions (tribological conditions).

Considering a large number of influential factors, as well as their mutual interaction, it is not always possible to examine the individual effects of each factor onto the output properties of the process with certainty. In laboratory investigations, especially in investigations performed on models, many influential factors cannot be taken into consideration which requires some caution when making a conclusion on effects of particular influential factors.

Investigations were performed on steel sheet metal samples (Č0148P3 - low carbon steel) and aluminium alloy sheet metal samples (AlMg3). Different strain ratio was realised by combination of suitable die cone semi-angle, α (α=5°; 10°; 15°; 20°) and blank holding force F_D (F_D = 8.7; 17.4; 26.1 kN).

As tool material (of die and punch), tool steel (AČ) and hard metal (TM) were used. Some contact pairs were coated with chrome (Cr), by hard chromium-plating, and with titan nitride (TiN). Punch roughness was varied, expressed by medium roughness height R_a (Ra=0.01; 0.09; 0.4 µm, which corresponds to quality of surfaces N1; N3; N5 respectively). As lubricants on contact surfaces, Li + MoS_2 – grease, then mineral emulsifying water-soluble oil with EP additives, as well as non-emulsifying means – paste and non-emulsifying mineral oil with mild EP properties were used.

Besides specified influential parameters, there is a whole other line of others, such as: polishing zone height, punch radius, work-piece bottom thickness, number of dies for drawing, ratio of inner and outer diameter of piece, ratio of dies diameters in multistage tool, ratio of piece height and diameter etc /3/, which have not been taken into consideration in this paper, due to objective reasons.

3. EXPERIMENTAL RESULTS

3.1 Single drawing

For analysing the influence of all accepted parameters on the ironing process, the principle of measuring the ironing force, as well as friction force on punch, was adopted; therefore, for every investigated sample (test-piece) there is a recorded diagram of specified forces change from punch travel (sliding path). Only characteristic trends of specified forces change on sliding path will be shown here.

It is characteristic that the ironing forces, on sliding path, can be constant (Figure 5a), increase (Figure 5c), or decrease (Figure 5b), which depends on contact conditions. Friction force on punch, also, can be decreasing (Figure 6a), constant (Figure 6b) or increasing (Figure 6c).

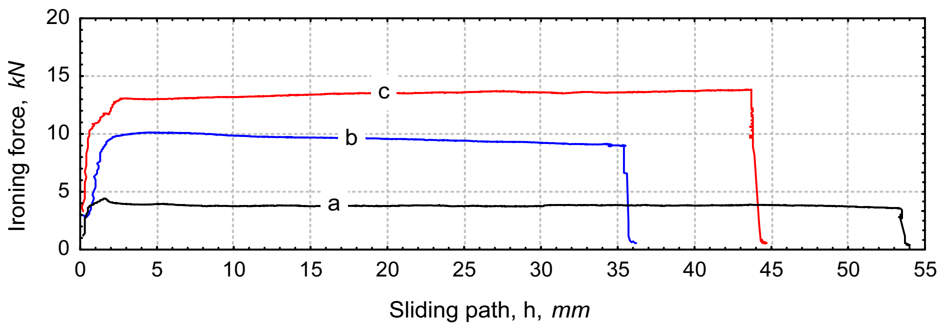


Figure 5: Example of constant (a), decreasing (b) and increasing (c) ironing force.

The force is constant when the selected lubricant is of a good quality. Inadequate lubricant with high viscosity most often leads to increase of force on sliding path, while lubricants with EP additives will lead to reduction of forces, i.e. friction, because these forces depend on friction on contact surfaces /4/.

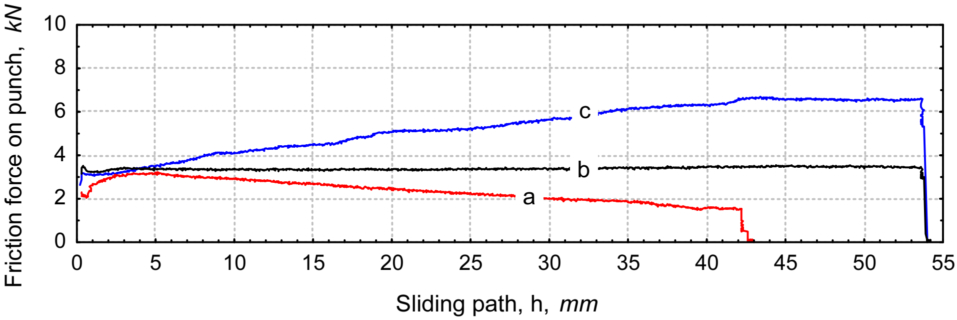


Figure 6: Example of decreasing (a), constant (b) and increasing (c) friction force on punch.

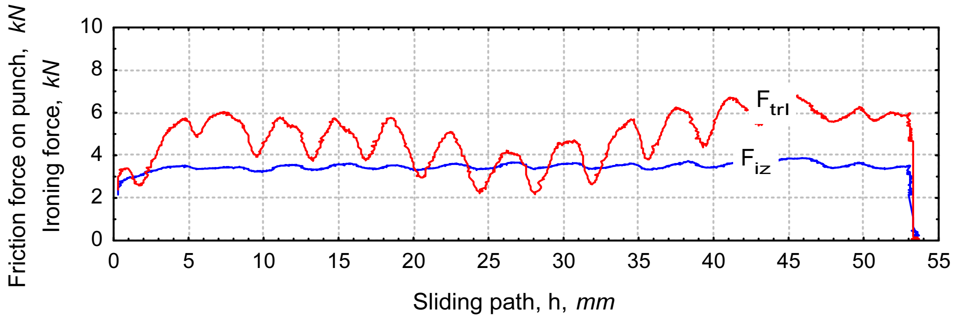


Figure 7: Example of oscillating friction force on punch (Ftrl) and ironing force (Fiz).

For some samples of aluminium alloy, another characteristic case of change of ironing force and friction force on punch has appeared (Figure 7), and that is the oscillatory character of forces. This case appears only at appropriate combination of lubricants on die side and on punch side and does not represent the well known appearance of "*stick-slip"* /5/.

In addition to specified trends of ironing force and friction force change on punch, instability of specified forces on sliding path was also observed (Figure 8 and Figure 9). Instability most often occurs due to inadequate lubricant or due to periodical creation of glued particles and their occasional breaking off.

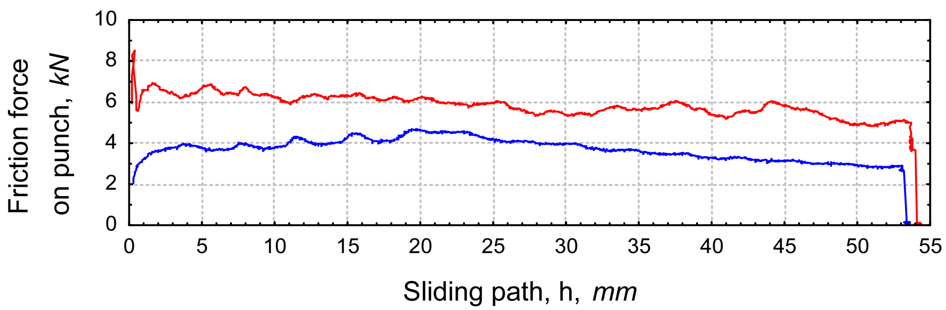


Figure 8: Example of unstable friction force on punch (Ftrl).

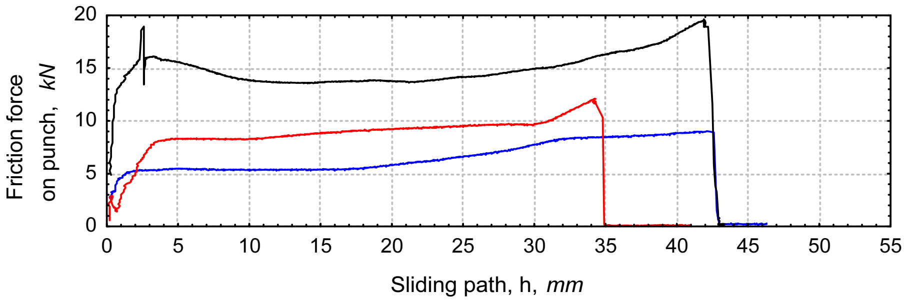


Figure 9: Example of unstable friction force on punch (Ftrl) when using inadequate lubricants.

3.2 Successive (multistage) drawing

In the ironing process, if it is necessary to achieve higher strain ratio, which would be possible without interoperation annealing, the drawing is performed successively through several dies. Thereat, due to change of contact conditions (extrusion of lubricant, change of surface roughness, creation of diffusion and adhesion connections etc), friction conditions change as well.
The investigation procedure consists of putting back one and the same test-piece into the initial position after a single ironing, after which it is ironed again, but the punch travel is always somewhat smaller than in the previous passage in order to preserve a part of test-piece surface for the additional analysis (measuring of hardness, roughness etc) /6/. In some cases, the test-piece surface on die side is lubricated only at the beginning of investigation, and in other cases it is lubricated before each ironing, which will be emphasised later in the results analysis. If lubrication was performed before each ironing, then the tool surface was cleaned from oxides (samples of Č0148P3) and glued particles (samples of AlMg3), if these appeared. Test-piece surface on punch side was always lubricated only before the beginning of the first drawing. The number of ironings was 2 to 4. The appearance of test-pieces after multistage drawing is shown in Figure 10.

Figure 10: The appearance of test-pieces after multistage drawing

At multistage drawing after each passage, completely new conditions are created on contact surfaces which significantly influence the ironing force. Characteristic changes of ironing force from sliding path at different passages, both for samples of Č0148P3, and for samples of AlMg3, are given in Figures 11 and Figure 12, respectively. On steel sheet metal samples, if lubrication is performed only at the beginning and at higher blank holding forces, significant dis-

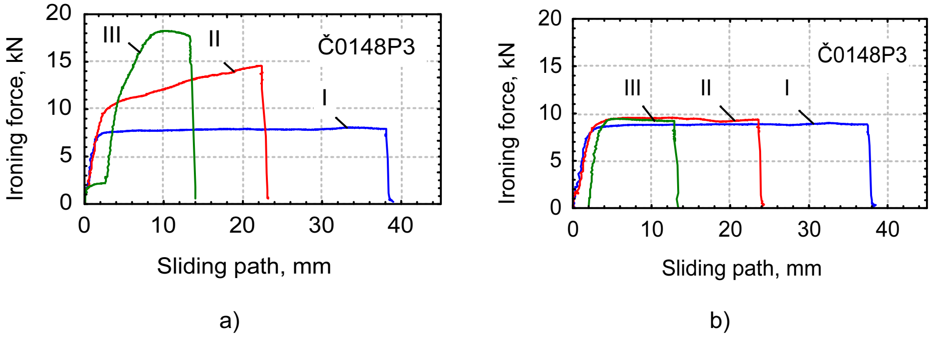


Figure 11: Change of ironing force at multistage drawing of steel sheet metal samples.

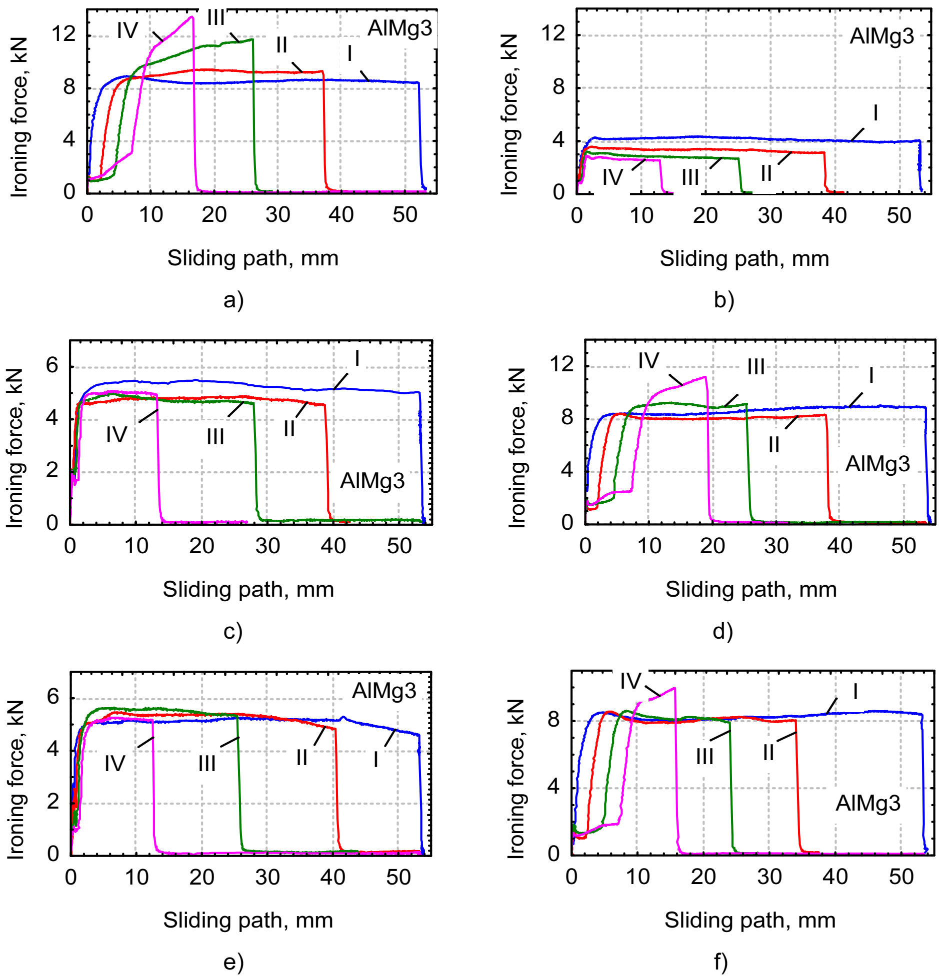


Figure 12: Change of ironing force at multistage drawing of alloy AlMg3 samples.

ruption of contact conditions occurs, which leads to prominent increase of ironing forces at each following passage (Figure 11a). If lubrication is performed before each passage, and die surface cleaned from created oxides, then, after the first passage, small increase of ironing force, which stabilises after that, will occur (Figure 11b).

On alloy AlMg3 samples, several characteristic cases of ironing force change in comparison with steel samples were observed. The reason for that are a larger number of applied lubricants as well as tendency of aluminium to creation of glued particles. When applying inadequate lubricants and with the effects of higher blank holding forces, creation of glued particles and significant disruption of contact conditions occur regularly, which leads to prominent increase of ironing force at each following passage (Figure 12a). If blank holding forces are small, and lubricants inadequate, then in the second passage ironing force can decrease, but already in the following passages its intensive increase is observed (Figure 12d). If blank holding forces are small, and lubricant is adequate (good), then at each following passage ironing force decreases (Figure 12b). At larger blank holding forces and appropriate lubricants, glued particles of aluminium on die were very small (after each passage the die was cleaned) or there were not any, which, in the following passages, influenced the ironing force either to increase slightly or to decrease slightly in relation to the first passage (Figures 12c and 12e). If the die was not cleaned after each passage, then, due to accumulation of glued particles, deterioration of friction conditions might occur after several passages, which would lead to increase of ironing force which was stable in the previous phases (Figure 12f).

4. CONCLUSION

Ironing force represents a very important value in the ironing process, because the consumed power (energy) for process execution depends on it. On the other hand, ironing force represents output value of the process, together with piece quality. Ironing force depends, more or less, on all relevant process parameters investigated in this paper (lubricant, tool material, punch roughness, die gradient angle and blank holding force).

For the ironing force it is characteristic that, on sliding path, it can be constant, increasing or decreasing, and in some cases it can have oscillatory (with some lubricants) and unstable character, which depends primarily on contact conditions.

At multistage drawing, after each passage, completely new conditions are created on contact surfaces which have very important influence both on ironing force and piece surface quality.

At drawing AlMg3 sheet metal, lubricant plays an important part – to separate sheet metal surface from tool and to prevent creation of glued particles on tool, considering a strong tendency of aluminium to gluing.

5. LITERATURE

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